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Innovative Solutions for Sustainability

Annual CSP Review Meeting

May 17-19, 2011

Development of Molten-Salt Heat Transfer Fluid Technology for Parabolic Trough Solar Power Plants

(DE-FC36-08GO18038)

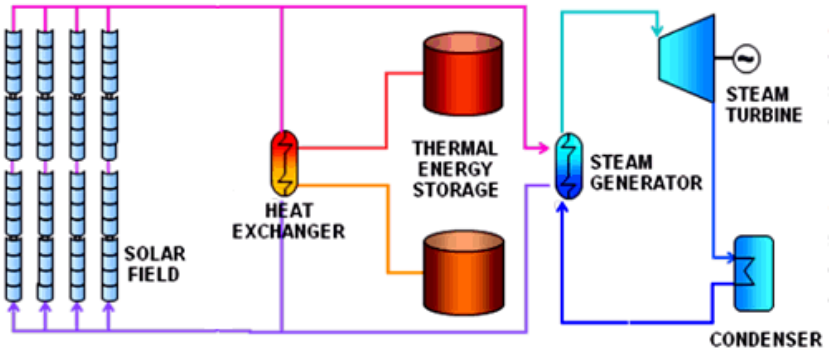
Presentation Outline

- Technology overview
- Project objectives and goals
- Challenges, barriers, and problems addressed
- Project schedule
- Project summary to date
- Phase 2 progress details
- Future work planned

Technology Overview

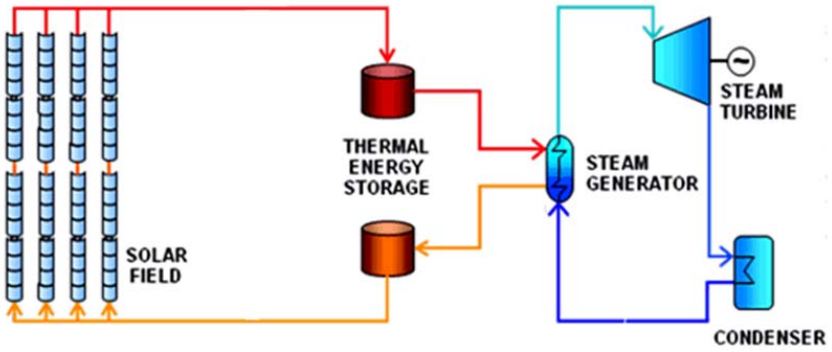
Today's Plant: Baseline

- 125 MW_{net}
- 6 hr indirect molten salt TES
- HTF: Therminol® VP-1
- ~400ºC maximum temperature
- 5.7m aperture collector



Tomorrow's Plant: Molten Salt

- 125 MW_{net}
- ~6 hr direct molten salt TES
- HTF: Hitec XL
- 500-550ºC maximum temperature
- Large aperture collector
- Fewer/longer loops
- Dry cooling



Objectives

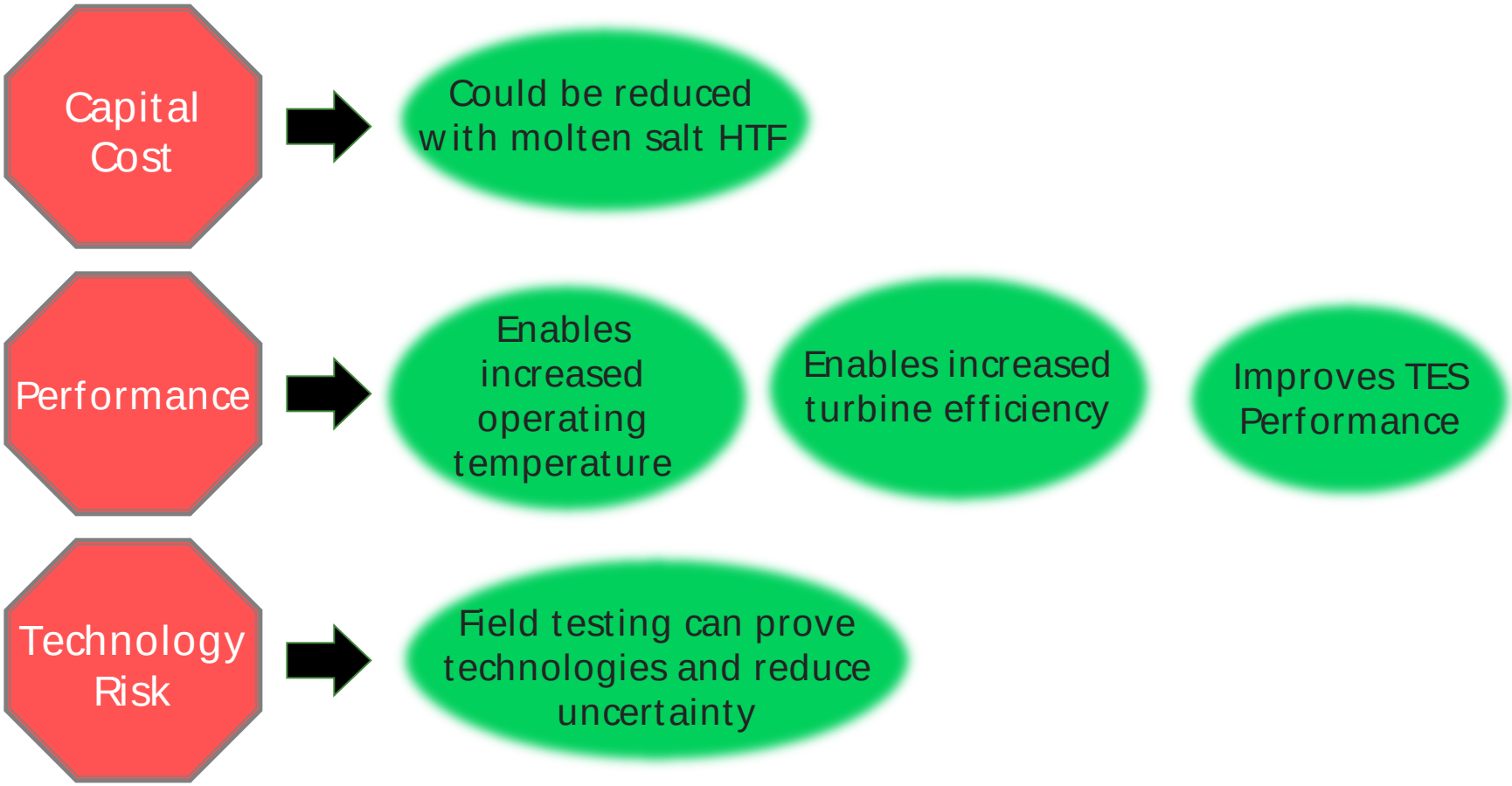
Determine whether inorganic fluids offer a sufficient reduction in levelized energy costs to pursue further development, and to develop the components required for the use of molten salt use; i.e., ball joints seals. This will occur in three steps:

- Short-term: Determine the concept feasibility and economic potential for replacement of the current generation of organic heat transport fluids with low freeze point molten salts.
- Medium-Term: Develop the technologies required for the use of molten salts.
- Long-Term: Conduct the field tests necessary for the introduction of molten salts in a commercial project.

Goals

- Phase 1
  - ≥ 10% reduction in LCOE over baseline or attributes of similar value
  - all key risk areas are being addressed
- Phase 2
  - $0.12/kWh in 2009 dollars with 10% ITC
  - all key risk areas are being addressed
- Phase 3 – T.B.D.

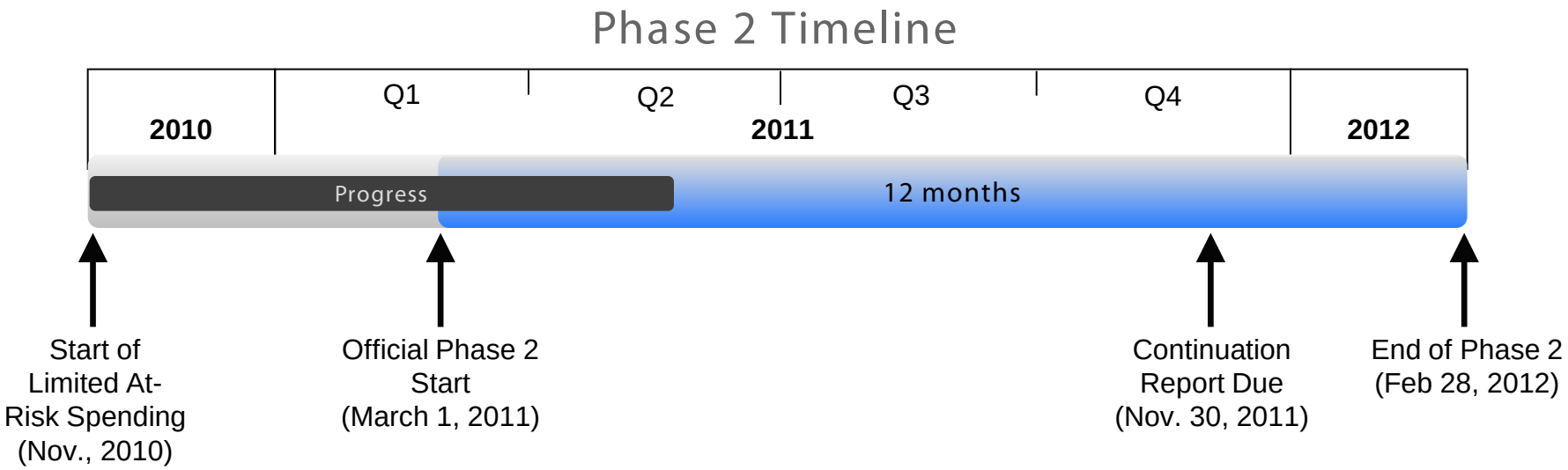
Industry Challenges, Barriers or Problems Addressed*



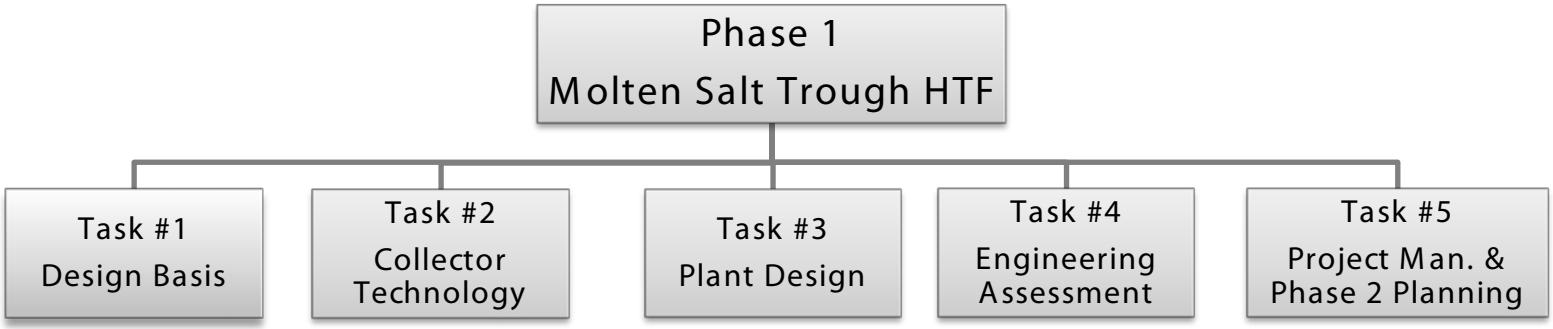
** As defined in U.S. DOE Solar Energy Technologies Multi Year Program Plan 2008-2012*

Project Schedule

- Phase 1
  - started – April 1, 2008
  - completed – June 30, 2010
- Phase 2
  - started – March 1, 2011
  - ~30% complete (on-schedule)

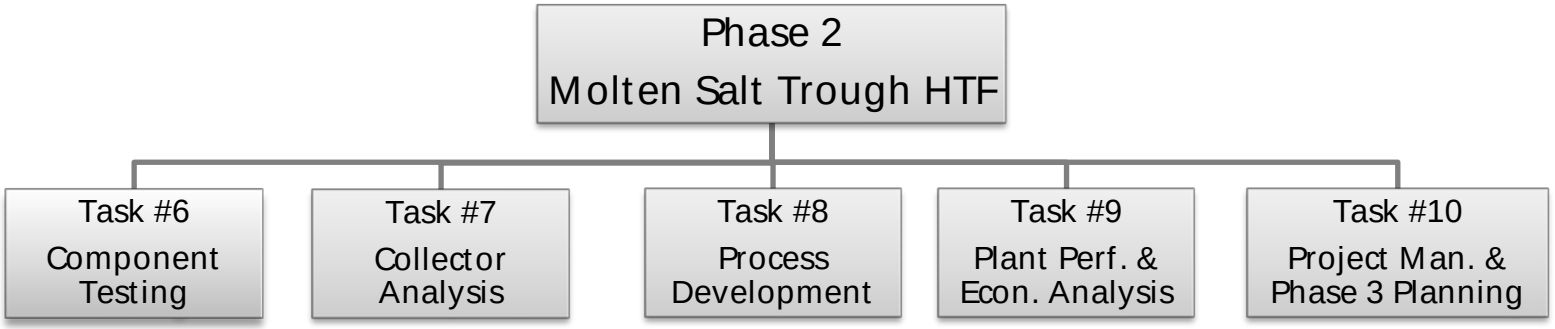


Project Summary to Date



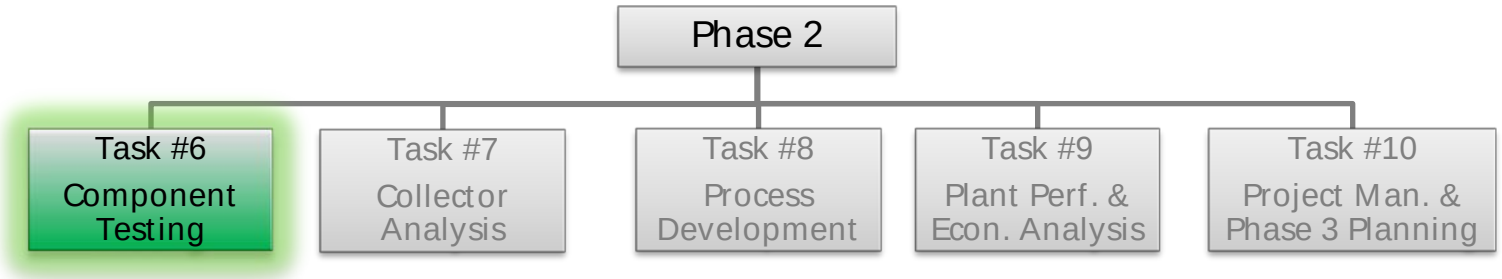
- Phase 1
  - Solutions proposed for all technical challenges of molten salt HTF
  - Molten salt enables direct TES which reduces cost/improves performance
  - Turbine efficiency increases due to increased steam temperature and pressure enabled by molten salt
  - Freeze protection and recovery system is significant cost
  - A molten salt based plant requires ½ of the salt needed for a equivalently sized synthetic oil plant with similar storage capacity
  - Potential for 9-15% LCOE reduction shown

Project Summary to Date (cont.)

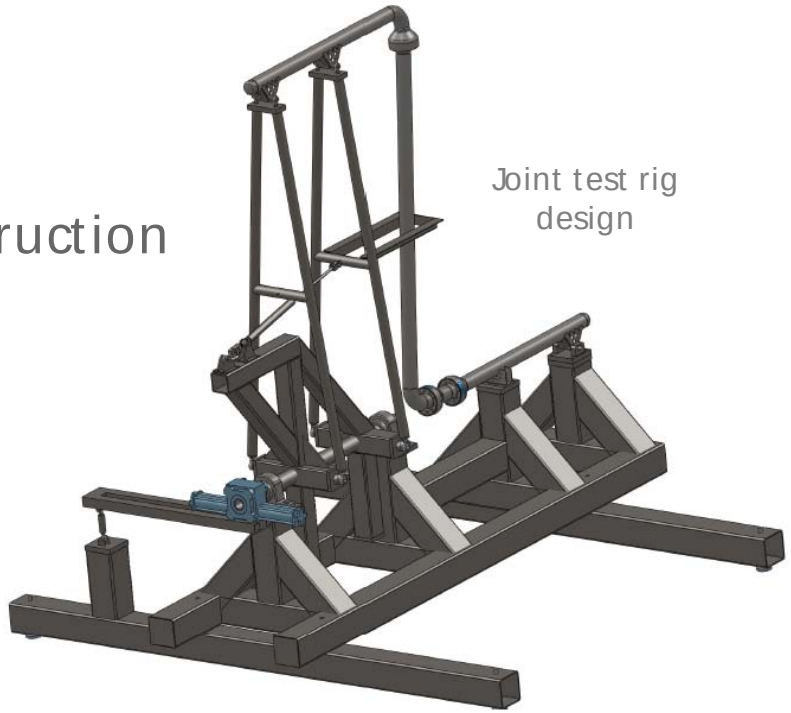


- Phase 2
  - Components ordered for testing
  - Joint test rig designed (Madison Scientific LLC)
  - Corrosion testing underway
  - Larger aperture collector with 90 mm receiver and no secondary chosen
  - Hitec XL thermophysical property testing underway
  - TRNSYS component model improvements underway

Phase 2 Progress-to-Date Detail

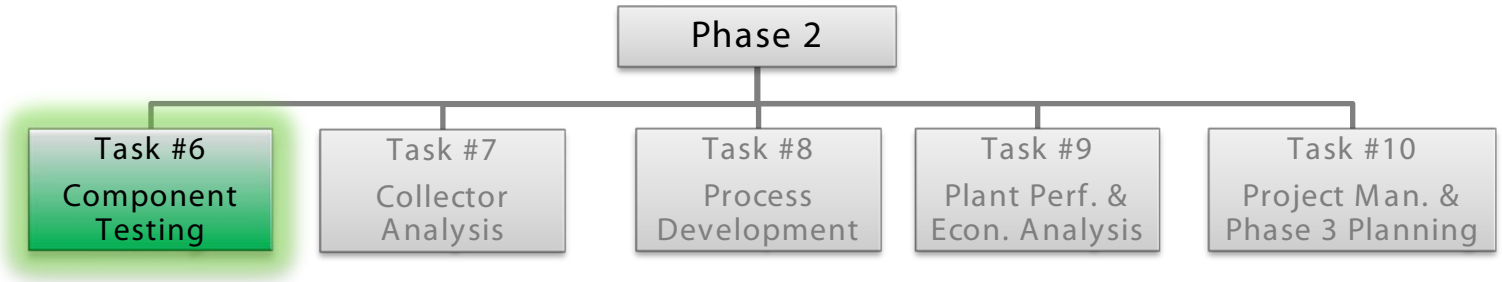


- Joints Ordered
  - American Thermal Systems ball joints
  - Blue Sky ball joints
  - Senior Berghöfer ROTATIONFLEX®-II
- Joint test rig designed & under construction (Madison Scientific LLC)
- Valves ordered
  - Dresser (globe)
  - Flowserve (globe)
  - Tyco (triple-offset)
- Pressure sensor ordered - NaK



Joint test rig design

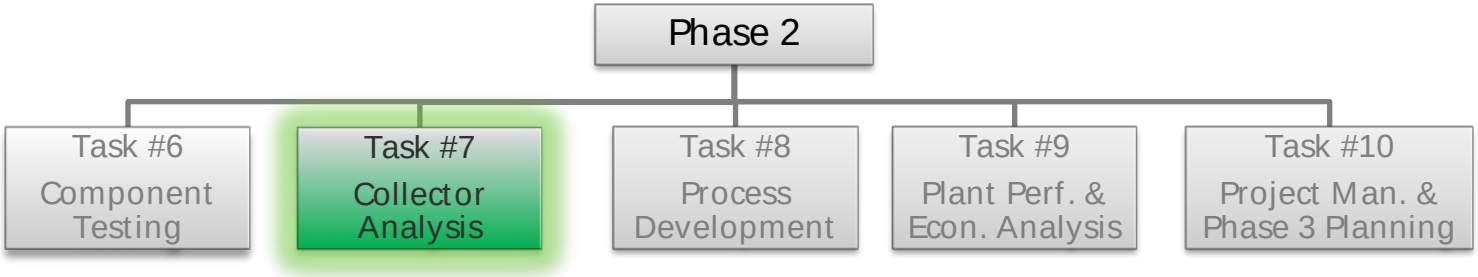
Phase 2 Progress-to-Date Detail



- Receiver material testing
  - Salt fog (ASTM B117)
    - 5% atomized NaCl solution at +35 °C for 1000 hrs
    - Completed
    - Material analysis underway
  - Salt bath (Sandia)
    - 3000 hr Hitec XL salt bath (0.5-0.6% Chloride)
    - Thermal cycled and constant temperature
    - Starting in May, 2011
- Freeze Protection/Recovery
  - Engineering underway for loop and other components

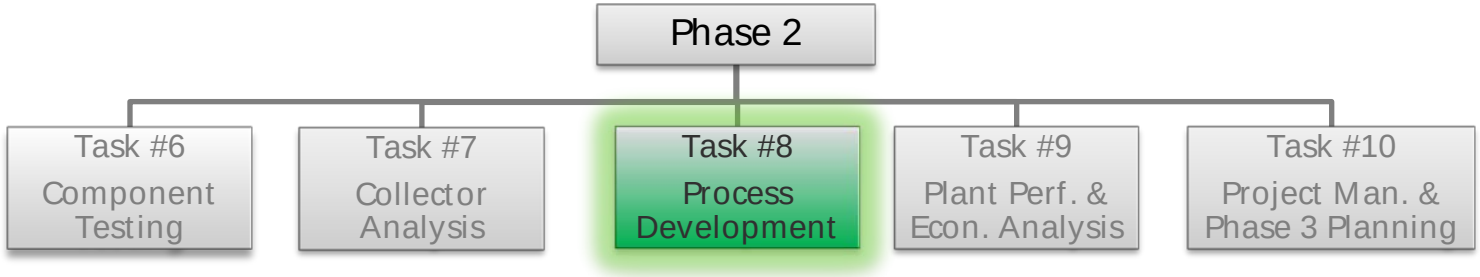
Salt Fog coupon at 1000 hrs

Phase 2 Progress-to-Date Detail



- Increased concentration study (7.5m aperture trough)
  - 90mm receiver favored
  - Longer loops favored
  - Significant impact of Freeze P/R cost on receiver tube choice
- Secondary reflector (SR) analysis (7.5m aperture trough)
  - 500ºC: SR design will not be pursued
  - 550ºC: SR design shelved until 550ºC is realistic
  - Cost limits on seeking optical improvements ~$37.50/m per 0.01 optical intercept

Phase 2 Progress-to-Date Detail



- Hitec XL properties ($NaNO_3$, KNO_3, $Ca(NO_3)_2$)
  - Uncertainty about eutectic point & melt temperature
  - Melt point as low as 120°C found in DSC
    - 15% $NaNO_3$, 43% KNO_3, 42% $Ca(NO_3)_2$
  - Glassification issue found
    - Experienced on cooling (may be related to rate)
    - Results from combination of KNO_3 and $Ca(NO_3)_2$
    - Glass phase exists much below 133°C
- Freeze plug detection method
  - 2 methods identified
  - Preparing for testing (NREL)

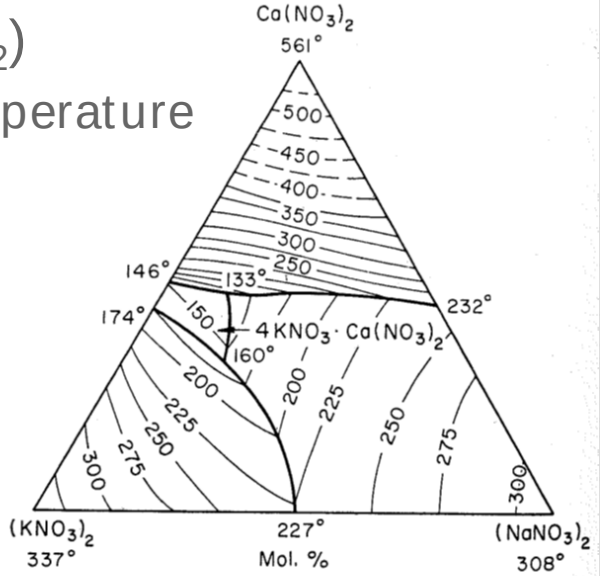
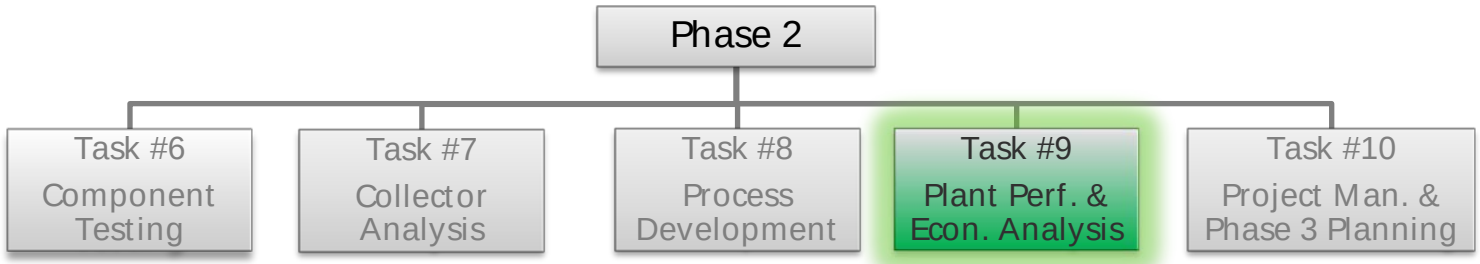


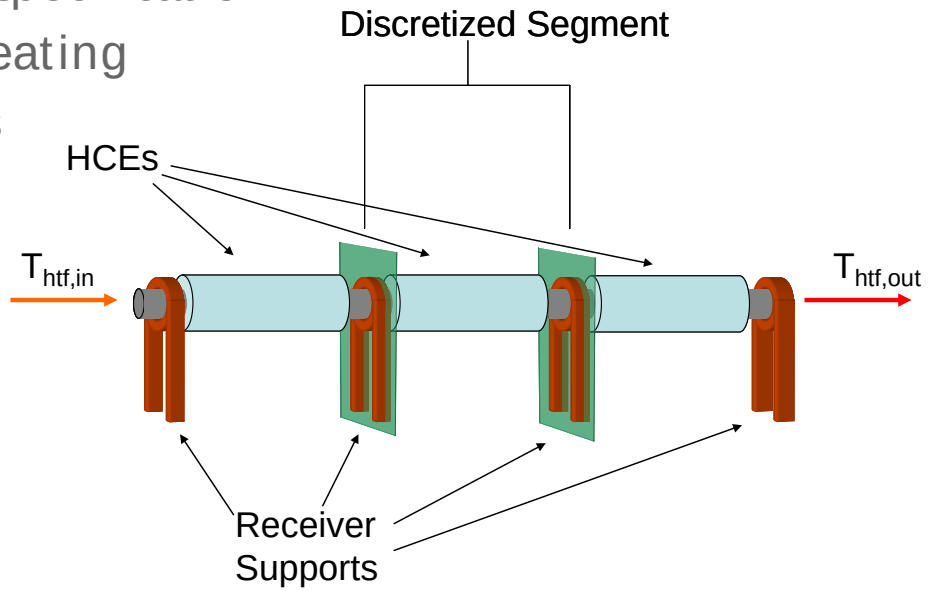
FIG. 1074.—System $(KNO_3)_2$–$(NaNO_3)_2$–$Ca(NO_3)_2$.

A. G. Bergman, I. S. Rassonskaya, and N. E. Shmidt, *Izvest. Sektora Fiz.-Khim. Anal., Inst. Obshcheĭ Neorg. Khim., Akad. Nauk S.S.S.R.*, **26**, 156 (1955).

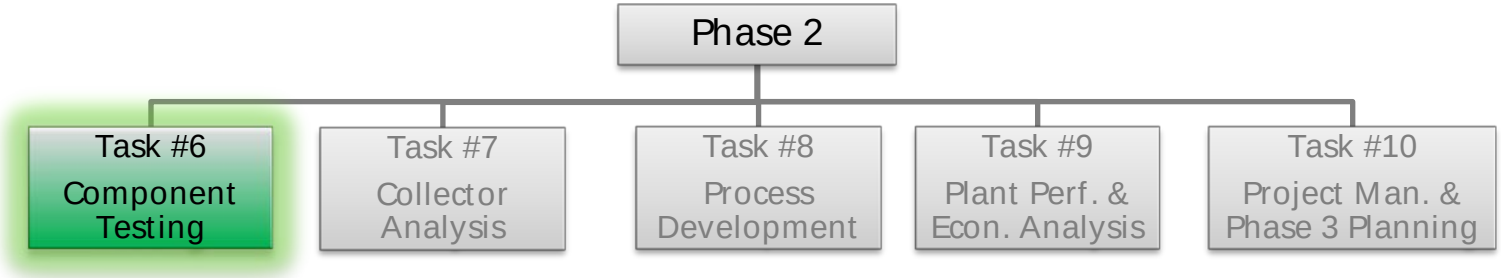
Phase 2 Progress-to-Date Detail



- Physics-based discretized loop solar field model
  - Based on Forristall's 1-D receiver model
  - Increase flexibility for receiver specification
  - Source terms for joule effect heating
  - Pathway for future capabilities

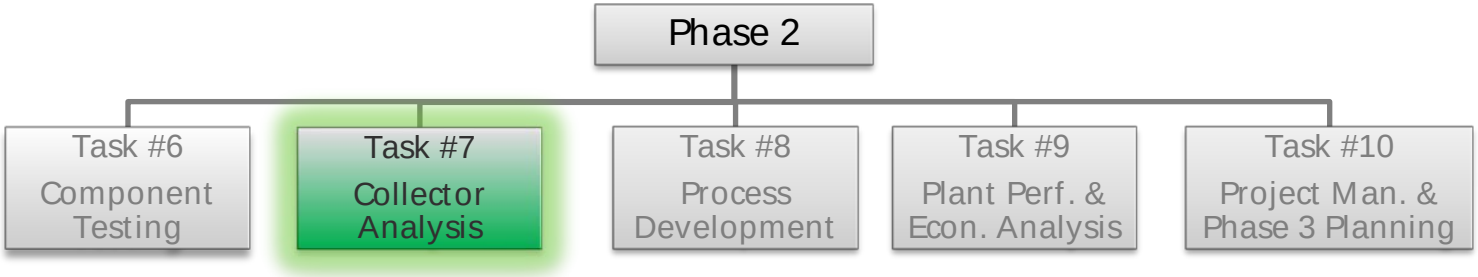


Phase 2 Future Work



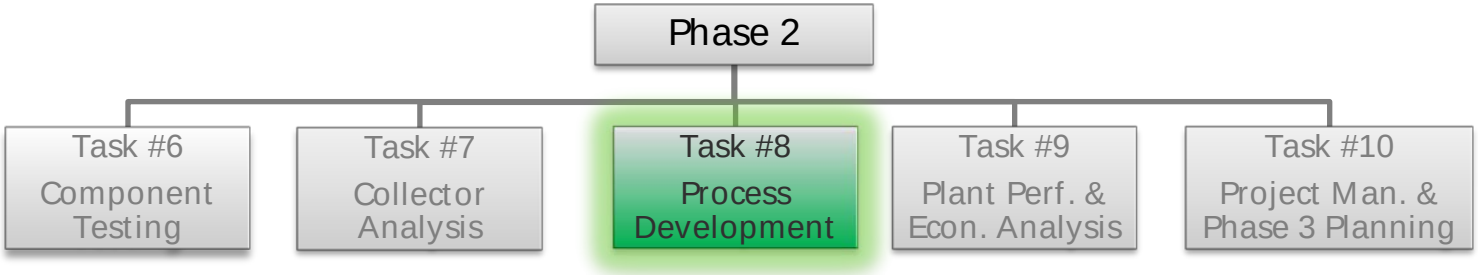
- Complete valve test rig design/construction (Madison Sci. LLC)
- Complete component testing (University of Wisconsin-Madison)
  - Joints
  - Valves
  - Instruments
- Complete corrosion testing/analysis (Sandia)
- Freeze protection/recovery system engineering

Phase 2 Future Work



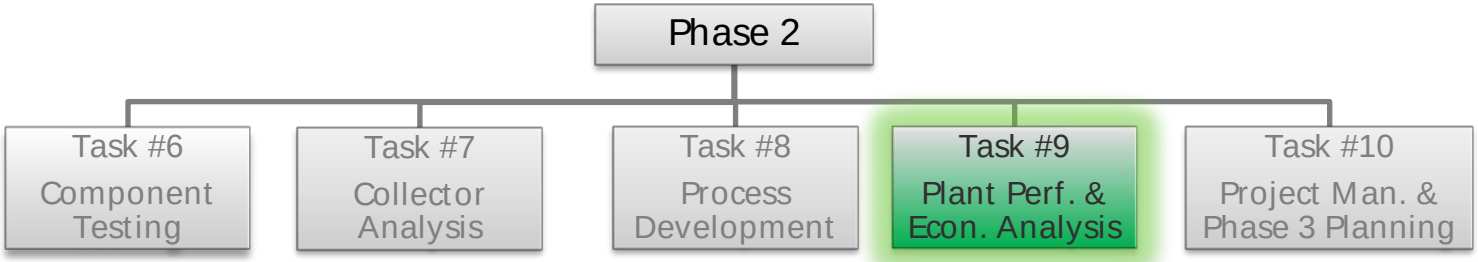
- Complete collector design modifications for salt
  - Starting from GO18037 collector
  - Additional receiver loads
  - Freeze protection/recovery system accommodations
    - mass
    - mounting
    - electrical isolation
  - Collector joint torque
  - Increased receiver growth

Phase 2 Future Work



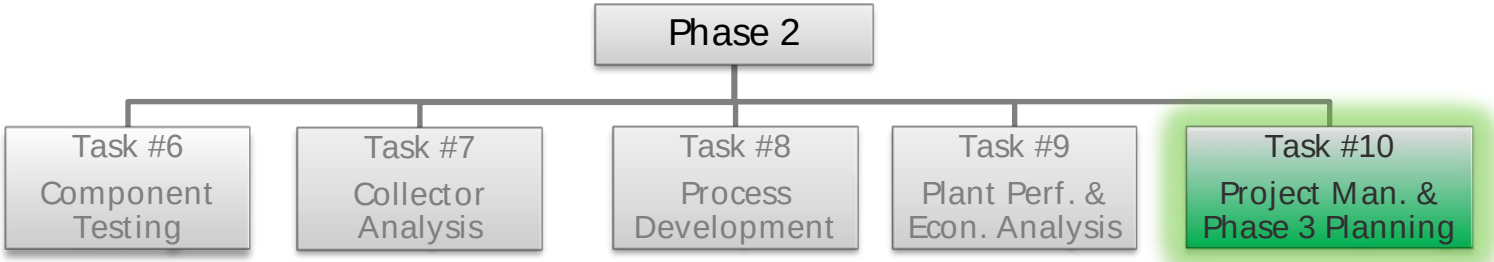
- Complete experimental measurement of Hitec XL
  - Eutectic point
  - Phase transition properties
  - Liquid thermophysical properties
  - Solid thermophysical properties
  - Understanding of glassification behavior/properties
- Complete testing of salt plug detection methods
- Prepare freeze protection/recovery procedure

Phase 2 Future Work



- Improved power block model
- Heat exchanger model
- Improved piping model
- Basic engineering of commercial plants to compile EPC cost estimate
- Analysis of field outlet temperature upper limit
- Analysis of alternate plant configurations
- Global plant optimization
- Final calculation of performance and LCOE

Phase 2 Future Work



- Detailed engineering of Phase 3 pilot plant plus quotes
- Continuation report (assuming Phase 2 goals met)

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Thank you